A REVIEW OF PEDIATRIC PEDESTRIAN INJURIES AT A LEVEL I TRAUMA CENTER

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ABSTRACT

Understanding the etiology of pediatric pedestrian-motor vehicle injuries requires a complete understanding of the distribution of these injuries by severity, body region, and age. A review is presented of injuries to all pediatric pedestrian crash victims that survived to presentation to a pediatric level one trauma center (Children's National Medical Center, Washington, D.C., USA). The data is a retrospective review of the pediatric trauma registry. The data consists of 4,887 injuries in 1,629 patients (ages 0 to 18 years). The overall injury distributions confirmed the findings of earlier studies showing the head and lower limbs to be the most vulnerable body regions. For the head, the rate of soft tissue injuries and severe injuries decreased with increasing age of the pedestrian. For the lower limb, a transition between femur and tibia/fibula injuries occurred as the child matured. This data should help prioritize areas of focus in developing vehicle countermeasures for the pediatric pedestrian population.

INTRODUCTION

Pediatric pedestrian injuries constitute a severe problem in motorized societies throughout the world. In the U.S., pedestrian injuries account for 61% of all pediatric trauma hospital admissions [1]. While the gross distribution of pediatric pedestrian-motor vehicle injuries has been described [2,3], the types of specific injuries suffered by child pedestrians hit by motor vehicles have, to the authors' knowledge, not been documented. Additionally, none of these studies has described the injuries sustained in detail, except to note the general injured region of the body. Although textbooks claim a varying injury distribution between young children, older children and adults, no data is referenced to define this difference [4,5].

The aim of the present study is twofold; to categorize the distribution of injuries encountered by pediatric pedestrians hit by motor vehicles and to gain understanding of how pedestrian-motor vehicle injury patterns change throughout childhood. An improved understanding of how these injury patterns vary across age groups should facilitate the development of vehicle countermeasures for both pediatric as well as adult pedestrian safety.

METHODS

The pediatric trauma registry at the Children's National Medical Center, Washington, DC, USA was searched to identify all children (aged 0 through 18 years) with pedestrian-motor vehicle injuries admitted to the trauma service from January 1988 until October 2002. A Human Investigation Committee review is waived for anonymous registry data.

The ICD-9 codes of all injuries sustained by the identified children were reviewed. For each patient, multiple listings of the same ICD-9 code were reduced to a single listing. In addition to the ICD-9 codes, the Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS) were used to describe injury severity as a result of trauma. The ICD-9 codes for the identified injuries were converted to AIS scores by use of the software ICDMAP-90 (The Johns Hopkins University & Tri-Analytics, Inc. 1998 - 2002). The same software was also used for calculating the ISS for each identified child.

ICD-9 codes provide explicit descriptions of many injuries and injury combinations. In order to improve analysis of data trends, the ICD-9 codes were reorganized into a smaller number of meaningful categories by body region and injury type. The body regions chosen were Head, Chest, Abdomen, Upper Extremity, Lower Extremity, Spine and Other. The injury types were in general only based on organ or anatomical location, for instance Liver or Knee. However, some of the injury types require further clarification. Injuries to the skin, peripheral blood vessels, peripheral nerves, as well as injuries to facial features (eye, ear, nose, mouth, etc.), were recoded as injuries to Soft Tissue. All types of intracranial hemorrhages were recoded as Hemorrhage. All identified ICD-9 codes describing brain tissue injury or prolonged (>24 hours) altered consciousness were considered to be of the type Severe Head Injury. All identified ICD-9 codes describing brief altered consciousness (<24 hours) or concussion were considered to be of the type Brief Loss of Consciousness (BLOC). Furthermore, ICD-9 head injury codes describing multiple injuries were subdivided and listed as separate injuries. For instance, a head injury coded as 800.22 (closed fracture of vault of skull with subarachnoid, subdural, and extradural hemorrhage, with brief (<1 hour) loss of consciousness) was separated and listed as two individual injuries; a skull fracture and a hemorrhage. Given the high associated frequency of lower extremity injury and considering that leg length increases rapidly during childhood, the changes in injury patterns are of particular interest. Therefore, injuries to the femur and tibia/fibula were further subdivided into more specific injury types based on injury location (proximal, mid-shaft, distal).

In order to analyze changes in injury patterns across age groups, the injury data were grouped according to the age groups 0 to 4 years, 5 to 9 years, 10 to 14 years and 15 through 18 years old. The selected age groups are consistent with previous pediatric injury literature [1,6]. For each body region and age group, the injury data were normalized and presented as injuries per 1,000 injured pediatric pedestrians of the same age group (Table 3). This normalization of the data allowed for comparison of injury rates among age groups.

RESULTS

The search of the pediatric trauma registry yielded 1,629 children of average age 7.9 years with a total of 4,887 ICD-9 coded injuries, and 5,113 injuries. The most common and second most common injuries sustained by the children were soft tissue injuries (2,319) and head injuries (1,332), respectively. These findings are in agreement with those of previous investigators [2,3]. The number of children and injuries in each of the four age groups, the average AIS scores for the injuries in each age group, and the average ISS for the children in each age group are provided in Table 1. Figure 1 shows the age distribution of the 1,629 patients.

Table 2 demonstrates the distribution of injury types by body region and age groups. Table 3 is a normalized version of Table 2 and contains the rates of all the different injury types by body region per 1,000 injured pedestrians in each age group. Tables 2 and 3 present the head injury data both as a distribution of injury types and a distribution of AIS scores. Table 4 shows the distribution of femur and tibia/fibula injury types and the rates of femur and tibia/fibula injury types per 1,000 injured pedestrians in each age group.

Table 1.
Patient demographics

Age (years)	0 - 4	5 - 9	10 - 14	15 - 19
Number of patients	311	776	464	78
Number of ICD-9 injuries	940	2307	1427	213
Number of injuries	986	2426	1480	221
Average AIS	1.93	1.97	1.97	1.87
Average ISS	7.51	6.96	7.93	5.31

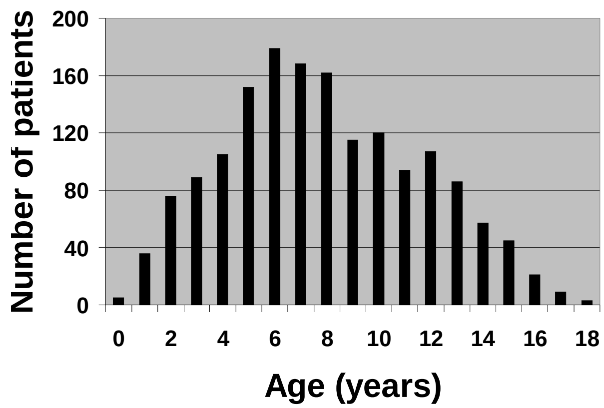

Figure 1. Age distribution of the 1,629 pediatric patients

DISCUSSION

This study reviews the distribution of injury types in the 1,629 pediatric victims of pedestrian-motor vehicle accidents admitted to the trauma service at the Children's National Medical Center in Washington, DC, USA from January 1988 until October 2002. The age distribution of the target population shown in Figure 1 suggests that the risk of being a victim of a pedestrian-motor vehicle accident increases from birth up to the age of 6 - 7 years and then declines up to the age of 18 years. This trend is roughly consistent with the findings of a previous study on pediatric pedestrian-motor vehicle injuries by DiMaggio et al. [1]. It should, however, be emphasized that DiMaggio and co-workers used police report data, which consequently would include those children who were hit by a motor vehicle but did not suffer injuries severe enough to require admission to trauma service and those children dead at the scene of the accident, neither of whom are included in the present study. The greatest difference between the age distribution in the present study and that in the study by DiMaggio et al. is the steep decline in frequency from age 13 to 18 years seen in

Table 2.
Distribution of injury types by body regions and age groups

Age (years)	0 - 4	5 - 9	10 - 14	15 - 18
Head				
Skull Fracture	26	53	27	2
Basilar Skull Fracture	15	39	23	3
Facial Fracture	13	29	21	6
Hemorrhage	37	91	46	2
Severe Head Injury	82	206	101	14
BLOC	114	221	128	33
Soft Tissue	270	588	310	48
Head				
AIS 1	279	619	326	52
AIS 2	164	387	222	47
AIS 3	29	77	41	5
AIS 4	29	85	45	2
AIS 5	33	64	24	6
AIS 6	0	0	1	0
AIS 9	27	91	42	4
Chest				
Lung	33	68	30	2
Clavicle	10	25	14	1
Vascular	0	1	0	0
Scapula	3	4	7	1
Chest wall	5	20	9	0
Heart	1	1	5	0
Abdomen				
Bowel	5	2	2	0
Diaphragm	0	4	0	0
Liver	14	16	6	1
Spleen	8	21	10	0
Pancreas	2	2	0	0
Kidney/Adrenal	7	18	5	1
Bladder/Ureter	2	3	2	1
Other	1	10	2	0
Soft Tissue	58	117	64	7
Upper Extremity				
Shoulder	0	1	4	0
Humerus	11	22	32	3
Forearm	2	12	12	1
Hand/Wrist	0	10	10	0
Soft Tissue	33	89	83	8
Lower Extremity				
Pelvis	25	38	32	8
Hip/Acetabulum	1	3	2	0
Femur	49	191	71	5
Knee	0	4	20	6
Tibia/Fibula	37	151	160	27
Ankle/Foot	3	8	13	2
Soft Tissue	70	218	152	28
Other	0	1	0	0
Spine				
Cervical	4	19	2	4
Thoracic	0	2	0	0
Lumbar	0	1	3	2
Sacral	2	3	1	0
Soft Tissue (Neck)	1	2	2	0
Other				
Other	5	19	9	0
Burn	4	7	3	0
Soft Tissue	32	80	54	5
Multiple Injury	1	5	3	0

Table 3.
Rates of injury types by body regions and age groups per 1,000 injured pediatric pedestrians

Age (years)	0 - 4	5 - 9	10 - 14	15 - 18
Head				
Skull Fracture	83.6	68.3	58.2	25.6
Basilar Skull Fracture	48.2	50.3	49.6	38.5
Facial Fracture	41.8	37.4	45.3	76.9
Hemorrhage	119.0	117.3	99.1	25.6
Severe Head Injury	263.7	265.5	217.7	179.5
BLOC	366.6	284.8	275.9	423.1
Soft Tissue	868.2	757.7	668.1	615.4
Head				
AIS 1	897.1	797.7	702.6	666.7
AIS 2	527.3	498.7	478.4	602.6
AIS 3	93.2	99.2	88.4	64.1
AIS 4	93.2	109.5	97.0	25.6
AIS 5	106.1	82.5	51.7	76.9
AIS 6	0.0	0.0	2.2	0.0
AIS 9	86.8	117.3	90.5	51.3
Chest				
Lung	106.1	87.6	64.7	25.6
Clavicle	32.2	32.2	30.2	12.8
Vascular	0.0	1.3	0.0	0.0
Scapula	9.6	5.2	15.1	12.8
Chest wall	16.1	25.8	19.4	0.0
Heart	3.2	1.3	10.8	0.0
Abdomen				
Bowel	16.1	2.6	4.3	0.0
Diaphragm	0.0	5.2	0.0	0.0
Liver	45.0	20.6	12.9	12.8
Spleen	25.7	27.1	21.6	0.0
Pancreas	6.4	2.6	0.0	0.0
Kidney/Adrenal	22.5	23.2	10.8	12.8
Bladder/Ureter	6.4	3.9	4.3	12.8
Other	3.2	12.9	4.3	0.0
Soft Tissue	186.5	150.8	137.9	89.7
Upper Extremity				
Shoulder	0.0	1.3	8.6	0.0
Humerus	35.4	28.4	69.0	38.5
Forearm	6.4	15.5	25.9	12.8
Hand/Wrist	0.0	12.9	21.6	0.0
Soft Tissue	106.1	114.7	178.9	102.6
Lower Extremity				
Pelvis	80.4	49.0	69.0	102.6
Hip/Acetabulum	3.2	3.9	4.3	0.0
Femur	157.6	246.1	153.0	64.1
Knee	0.0	5.2	43.1	76.9
Tibia/Fibula	119.0	194.6	344.8	346.2
Ankle/Foot	9.6	10.3	28.0	25.6
Soft Tissue	225.1	280.9	327.6	359.0
Other	0.0	1.3	0.0	0.0
Spine				
Cervical	12.9	24.5	4.3	51.3
Thoracic	0.0	2.6	0.0	0.0
Lumbar	0.0	1.3	6.5	25.6
Sacral	6.4	3.9	2.2	0.0
Soft Tissue (Neck)	3.2	2.6	4.3	0.0
Other				
Other	16.1	24.5	19.4	0.0
Burn	12.9	9.0	6.5	0.0
Soft Tissue	102.9	103.1	116.4	64.1
Multiple Injury	3.2	6.4	6.5	0.0

Table 4.
Distribution of femur and tibia/fibula injury types and rates of femur and tibia/fibula injury types per 1,000 injured pediatric pedestrians

Distribution of Femur and Tibia/Fibula Injury Types				
Age (years)	**0 - 4**	**5 - 9**	**10 - 14**	**15 – 18**
Femur proximal	4	4	3	0
Femur mid-shaft	38	160	40	5
Femur distal	7	27	28	0
Tibia/Fibula proximal	2	13	19	6
Tibia/Fibula mid-shaft	30	130	127	20
Tibia/Fibula distal/ankle	1	8	14	1
Rates of Femur and Tibia/Fibula Injury Types per 1,000 Injured Pediatric Pedestrians				
Age (years)	**0 - 4**	**5 - 9**	**10 - 14**	**15 - 18**
Femur proximal	12.9	5.2	6.5	0.0
Femur mid-shaft	122.2	206.2	86.2	64.1
Femur distal	22.5	34.8	60.3	0.0
Tibia/Fibula proximal	6.4	16.8	40.9	76.9
Tibia/Fibula mid-shaft	96.5	167.5	273.7	256.4
Tibia/Fibula distal/ankle	3.2	10.3	30.2	12.8

the present study (Figure 1). The most likely explanation to this difference is that the data used in the present study are from a children's hospital and consequently that many older children and adolescents injured in pedestrian-motor vehicle accidents were treated at general hospitals.

Classification of the injuries by body region facilitates comparison among age groups. Therefore, discussion of the results is delineated by body region. It is important to note, however, that the observations are limited to injury trends and rates. Relationships between these rates and the corresponding environmental and vehicular risk factors require more detailed analysis of the crash reconstruction and subsequent pedestrian kinematics. In the absence of this information, however, the authors have attempted to suggest possible rather than definitive injury mechanisms where appropriate. These hypothesized mechanisms were developed based on the observed injury and the influence of body size on pedestrian kinematics and loads demonstrated in published computational investigations [7].

Head Injury

The head injury data in Table 3 indicate that the rate of Soft Tissue injury to the head is higher in younger than in older children. Examining AIS 1 and 2 head injuries confirm this trend. However, more severe (AIS 3+) head injuries appear to either remain unchanged or in some cases decrease with increasing age. For the more specific injury classifications, Table 3 demonstrates that the rates of Skull Fracture and Hemorrhage decrease with increasing age. These trends may be due to a combination of the head being less likely to be struck at the initial vehicle impact as the children grow taller or that younger children have lower injury tolerances.

Chest

For all four age groups, the most common type of chest injury is lung injury (Table 3). A plausible explanation to the trend of decreasing rate of lung injury with increasing age could be that the strength of the rib cage increases with age during maturation and thus, provides better protection for the underlying lungs. However, chest wall injuries were relatively rare for all age groups. This may suggest that even the older child's rib cage is sufficiently compliant to limit the number of rib fractures that occur.

Abdomen

The abdominal injury data in Table 3 demonstrate that the rate of kidney and adrenal injuries is similar to the rates of liver and spleen injuries. This is different than the injury pattern seen in child occupants in motor vehicles crashes for which the rate of liver and spleen injuries are higher than the rate of kidney and adrenal injuries. In the vehicle environment, the kidneys are either remote from the point of load application in frontal crashes (e.g., a belt loading the anterior torso) or are partially protected by the vehicle seat for other impact directions. In pedestrian impacts, however, there can exist more narrowly focused loading of the unprotected abdomen by either the bumper or vehicle front.

Upper Extremity

Table 3 demonstrates that the most frequently injured bone in the upper extremity is the humerus, although the occurrence of all upper limb injuries was relatively low. This injury pattern suggests that the most common cause of upper extremity injury is likely direct impact to the arm. The low rates of forearm and hand/wrist injuries (fractures) suggest that children are unable to try to protect themselves during either the primary impact with the vehicle or the secondary impact with the ground. If children were able to try to protect themselves, they would likely sustain a higher rate of the classic FOOSH (Fall On an Outstretched Hand) injuries.

Lower Extremity

Previous empiric data have suggested a varying distribution of lower extremity injuries with different child size [4], but no authors have documented the nature or extent of these differences. The results from the present study suggest that femur injuries are more common in younger than in older children but that older children are more likely to suffer tibia/fibula and ankle/foot injuries than younger children. Ashton et al. have demonstrated a strong correlation between height of the bumper or hood leading edge and the location of injury [8]. The reduction in femur injuries and increase in tibia/fibula injuries as the child ages (i.e., grows) would seem to support this claim. However, the change in contact injury location does not migrate from mid-shaft femur to distal femur to proximal tibia to mid-shaft tibia as would be expected as the height of the bumper relative to the limb decreases with increasing age of the pedestrian. Rather, most of the femur and tibia fractures were mid-shaft regardless of the age of the pedestrian. However, our results demonstrate a much higher rate of knee injury in the two oldest age groups than in the two youngest age groups. While knee injuries do occur when the leading edge of the vehicle is at knee height [9], injuries of the knee can also occur with translation of the femur or tibia if initial fracture on contact does not occur. We hypothesize that the increase in knee injuries for the older children may result from both more contacts of the bumper to the knee and also from proximal leg contacts causing dislocation at the knee.

The majority of the pelvic fractures recorded in the study were single pelvic ring injuries, which agrees with the findings of previous investigators [10-12]. The rate of pelvic injuries appears highest in the youngest and oldest populations. The authors hypothesize that the bumper height may be sufficient to contact the pelvis of the younger children whereas the vehicle front and hood leading edge could contribute to pelvic injuries for the older population. The drop in rate for the 5-14 year old age groups may suggest that their pelvis height lies between the bumper and hood leading edge.

Although the present work sheds further light upon the distribution, and possibly the cause, of pediatric pedestrian-motor vehicle injuries, the data have some inherent limitations. The data can not account for the type of impact and do not include information on the distribution of vehicle body types involved in the accidents. It is unknown what percentage of children were driven over or crushed, what percentage involved forward projection, or what percentage impacted the top of the vehicle only to roll off onto the ground or another vehicle. Additional in-depth investigations involving crash reconstruction information must be coupled with large trauma databases to develop not only injury priorities but also directions for countermeasure development.

CONCLUSIONS

These data confirmed earlier studies showing the prevalence of head and lower limb injuries for the pediatric pedestrian population struck by a motor vehicle. In addition, the paper provides a more descriptive distribution of pediatric pedestrian-motor vehicle injuries than has been previously reported. For the head, the rate of soft tissue injuries and severe head injuries decreased with increasing age of the pedestrian. For the lower limb, a transition between femur and tibia/fibula injuries potentially highlights the significance of considering bumper height for a range of pedestrian anthropometries. In general, this work supports further investigations into the height of vehicle components relative to the anthropometry of the pedestrian. Furthermore, the age-dependent distribution of injuries suggests that priorities for optimizing vehicle countermeasures may depend on the age and size of the pedestrians.

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